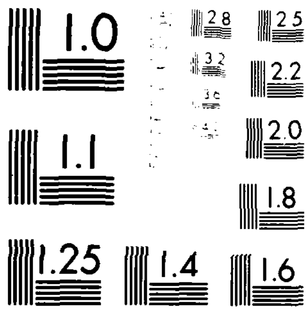
AD-A123 072 SATELLITE MEASUREMENTS OF ATMOSPHERIC AEROSOLS(U) 1/1
SCIENCE APPLICATIONS INC LA JOLLA CA M GRIGGS
22 DEC 82 SAI-131-82-343LJ N00014-77-C-0489

UNCLASSIFIED F/G 20/1 NL

END
DATE
FILMED
3-83
DTIC



MICROCOPY RESOLUTION TEST CHART

12

AD A 123672

SCIENCE APPLICATIONS, INC.

SAI-131-82-343LJ

ANNUAL REPORT

CONTRACT N00014-77-C-0489

SATELLITE MEASUREMENTS OF ATMOSPHERIC AEROSOLS

December 22, 1982

Principal Investigator:

M. Griggs
Science Applications, Inc.
Electronic Vision Systems Division
11526 Sorrento Valley Road, Suite A
San Diego, California 92121

Prepared for:

Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217

SCIENCE APPLICATIONS, LA JOLLA, CALIFORNIA
ALBUQUERQUE • ANN ARBOR • ARLINGTON • ATLANTA • BOSTON • CHICAGO • HUNTSVILLE
LOS ANGELES • McLEAN • PALO ALTO • SANTA BARBARA • SUNNYVALE • TUCSON

P.O. Box 2351, 1200 Prospect Street, La Jolla, California 92037

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: SAI-131-82-343LJ	2. GOVT ACCESSION NO.: AD [illegible]
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Satellite Measurements of Atmospheric Aerosols	5. TYPE OF REPORT & PERIOD COVERED: Annual Report, October 1, 1981 to November 30, 1982
	6. PERFORMING ORG. REPORT NUMBER: SAI-131-82-343LJ
7. AUTHOR(s): M. Griggs	8. CONTRACT OR GRANT NUMBER(s): N00014-77-C-0489
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Science Applications, Inc. P. O. Box 2351 La Jolla, CA 92037	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Naval Research, Code 465 800 North Quincy Street Arlington, VA 22217	12. REPORT DATE: December 22, 1982
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same as report.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Maritime Aerosols
Satellite Measurements
Error Analysis
Ocean Radiance
Aerosol Scattering
Sun Photometer Measurements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Analysis of NOAA-6 AVHRR data and ground truth measurements at Midway show excellent agreement between the satellite inferred values of aerosol optical thickness and the ground truth values. Similar agreement was found previously at San Diego and on the USNS Hayes in the Atlantic Ocean, suggesting that the satellite technique for measuring tropospheric aerosols has global application.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

ABSTRACT

Analysis of NOAA-6 AVHRR data and ground truth measurements at Midway shows excellent agreement between the satellite inferred values of aerosol optical thickness and the ground truth values. Similar agreement was found previously at San Diego and on the USNS Hayes in the Atlantic Ocean, suggesting that the satellite technique for measuring tropospheric aerosols has global application.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

The investigation of the satellite technique[1,2,3] to measure tropospheric aerosols over the ocean has continued with more analysis of ground truth data using the single channel method[1,2] prior to using the two channel method[3]. An invited paper, which included the two channel analysis developed in this investigation, was presented at the XXIV COSPAR Meeting in Ottawa, Canada, May 24-26, 1982, and is included in this report.

2. ANALYSIS OF MIDWAY DATA

The analysis of the data set obtained at Midway in 1980 has been initiated using the single channel method, and will later use the two channel table look-up (TLU2) computer code developed under NEPRF sponsorship[4]. The Midway results presented here used only AVHRR Channel 1.

The Midway data set turned out to be of poor quality with cloudy conditions often being recorded by the ground observer; these conditions were verified by the AVHRR data which often showed considerable variability of the radiance from pixel to pixel. However, it was found that the radiance of one of the pixels within three pixels (~12 km) of the estimated ground truth site generally gave good agreement with the ground truth. This is reasonable to expect considering the variability of the AVHRR radiances, since the location of the ground truth site is not precisely known in the AVHRR data; the presence of clouds smaller than the pixel size (4 km) would not be clearly detected but would enhance the pixel radiance; and, the atmosphere is moving in the time between the satellite and ground truth measurements which are typically up to twenty minutes apart.

The results of taking the best estimate of the satellite inferred value of the aerosol optical thickness are given in Fig. 1, and show excellent agreement between the AVHRR Channel 1 and ground-truth values. For comparison the results using the pixel closest to the estimated site location are given in Fig. 2. Even in this case the agreement is fair.

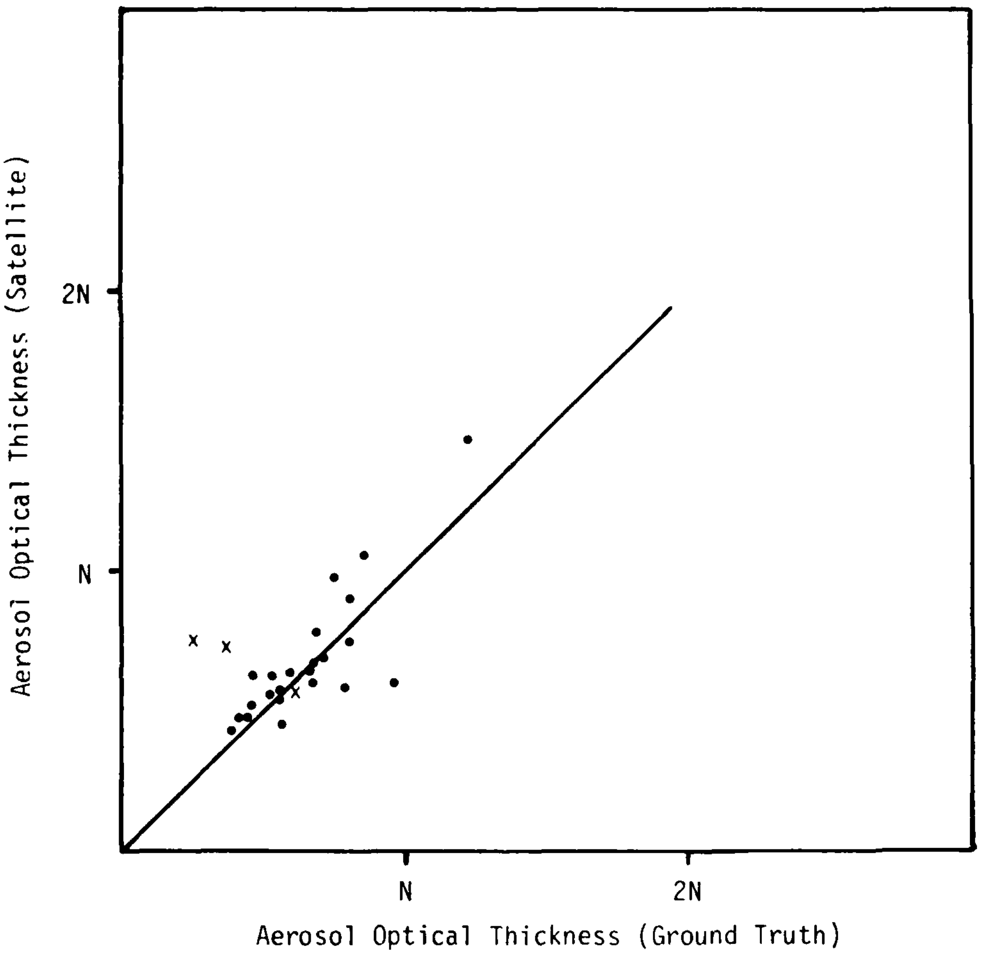


Figure 1. Comparison of AVHRR (Channel 1) and Ground Truth Measurements of Aerosol Optical Thickness at Midway Using Best Pixel (x indicates $\theta_o > 70^\circ$).

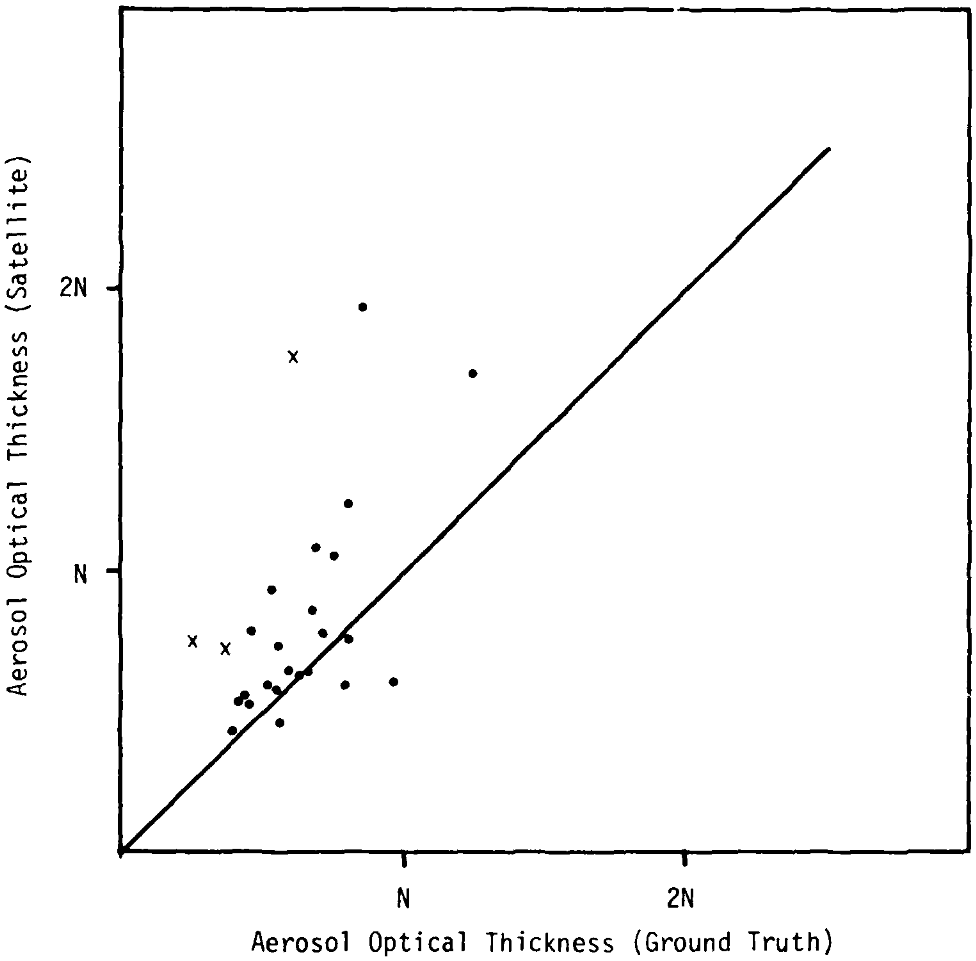


Figure 2. Comparison of AVHRR (Channel 1) and Ground Truth Measurements of Aerosol Optical Thickness at Midway (x indicates $\theta_o > 70°$).

3. CONCLUSIONS

In comparing these Midway results with those[3] obtained at San Diego and in the Atlantic on the USNS Hayes, it appears that there is no significant global variation of aerosol properties that would preclude using the AVHRR single channel method to measure the aerosol optical thickness over the oceans on a routine basis.

4. REFERENCES

1. M. Griggs, "Satellite Measurements of Atmospheric Aerosols," Annual Report, Contract N00014-77-C-0489 (March 31, 1979).

2. M. Griggs, "Satellite Measurements of Atmospheric Aerosols," Annual Report, Contract N00014-77-C-0489 (November 14, 1980).

3. M. Griggs, "Satellite Measurements of Atmospheric Aerosols," Annual Report, Contract N00014-77-C-0489 (August 26, 1981).

4. M. Griggs, "Satellite Measurements of Maritime Aerosol Parameters," Progress Report, Contract N00228-82-C-6199 (June 1982).

5. INVITED PAPER PRESENTED AT XXIV COSPAR MEETING IN OTTAWA, CANADA, MAY 1982

SATELLITE MEASUREMENTS OF TROPOSPHERIC AEROSOLS

ABSTRACT

The ability to measure tropospheric aerosols over ocean surfaces has been demonstrated using several different satellite sensors. Landsat data originally showed that a linear relationship exists between the upwelling visible radiance and the aerosol optical thickness (about 90% of this thickness is generally in the lowest 3 km of the atmosphere). Similar relationships have also been found for sensors on GOES, NOAA-5 and NOAA-6 satellites. The linear relationship has been shown theoretically to vary with the aerosol properties, such as size distribution and refractive index, although the Landsat data obtained at San Diego showed little variability in the relationship. To investigate the general applicability of the technique to different locations, a global-scale ground-truth experiment was conducted in 1980 with the AVHRR sensor on NOAA-6 to determine the relationship at ten ocean sites around the globe. The data for four sites have been analyzed, and show excellent agreement between the aerosol content measured by the AVHRR and by sunphotometers at San Diego, Sable Island and San Juan, but at Barbados, the AVHRR appears to overestimate the aerosol content. The reason for the different relationship at the Barbados site has not been definitely established, but is most likely related to problems in interpret[illegible] the sunphotometer data rather than to a real overestimation by the AVHRR. A preliminary analysis of AVHRR Channel 1 (0.65 μm) and Channel 2 (0.85 μm) radiances suggest that useful information on the aerosol size distribution may also be obtained from satellite observations.

INTRODUCTION

Tropospheric aerosols play an important role in environmental quality on local, regional, and global scales. The local and regional aerosols impact mainly on the ambient air quality, and changes in the global background levels of aerosols may affect our climate. The use of space observations for monitoring tropospheric aerosols on a quantitative basis has been limited to ocean areas [1,2,3]. Landsat data [4] were originally used to demonstrate that a linear relationship exists between the upwelling visible radiance and the aerosol optical thickness (essentially all of this thickness is in the troposphere) over oceans. Since that time, similar relationships have also been found for sensors on the GOES and NOAA-5 satellites [5]. The linear relationship has been shown theoretically to vary with the aerosol properties, such as size distribution and refractive index, although the Landsat data obtained at San Diego showed little variability in the relationship. Before this relationship can be used on a global basis to routinely monitor aerosols with satellite observations, it is necessary to investigate the possible variation of the relationship with location.

This work uses NOAA-6 AVHRR data and coincident ground-truth measurements of the aerosol optical thickness, obtained in 1980, to investigate the variability of the relationship at different ocean sites around the globe. The possibility of using AVHRR Channels 1 and 2 to infer information about the aerosol size distribution is also discussed.

The continued development of this technique can ultimately lead to an operational system using AVHRR data to routinely produce global ocean maps of aerosol optical thickness and, possibly the aerosol size distribution. These data would be of great importance for determining the background levels of aerosol loading for use in climate studies, and in tracking the movement of polluted air masses and desert dust outflows.

APPROACH

The relationships [1] between the upwelling visible radiance and the atmospheric aerosol content 1/ measured by Landsat 2 over the ocean at San Diego are shown in Fig. 1, and demonstrate the feasibility of measuring the aerosol content over oceans. In order to use this technique to routinely map global aerosol distributions it is preferable to use a satellite such as NOAA-6 to obtain daily coverage. The AVHRR Channel 1 on NOAA-6 has a spectral bandpass very similar to that of MSS5, with the same bandwidth of 0.1 μm, and centered at 0.645 μm in comparison with a center of 0.65 μm for MSS6. Thus, the radiance values measured with the AVHRR Channel 1 may be directly compared with those of MSS6. The AVHRR radiance data are recorded in a 10-bit digital system and are more sensitive to aerosol changes than the 7-bit MSS6 data.

The Landsat data are based on nadir viewing, whereas the AVHRR scans up to 60° from the nadir; thus, the MSS5 relationship in Fig. 1 cannot be used directly with AVHRR radiances to infer the aerosol content. To use the MSS5 relationship, theoretical calculations have been performed to relate the nadir radiance to the radiance at other viewing angles, as a function of sun angle and aerosol content. These calculations, made with the Dave [7] scattering code, have then been incorporated into a table-look-up algorithm so that the AVHRR radiance measurement together with the scan angle and sun angles can be used to infer the atmospheric aerosol content. The calculations use aerosol parameters such that the theory reproduces the linear regression found for the MSS5 data in Fig. 1.

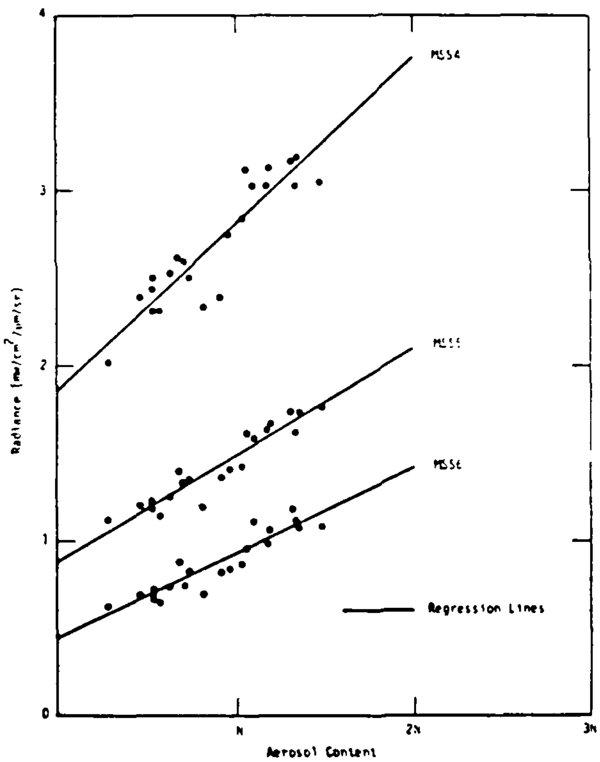


Fig. 1 Landsat Radiance vs Aerosol Content at San Diego for MSS4, MSS5 and MSS6. (Normalized to nadir viewing and a sun zenith angle of 63°)

1/ The aerosol content is defined in terms of the Elterman [6] model vertical aerosol optical thickness; i.e., the aerosol content is given by the ratio (measured aerosol optical thickness at wavelength λ to the model aerosol optical thickness at wavelength λ) x N. In the results reported here, the wavelength is always 0.5 μm, and the model aerosol optical thickness is 0.213 (to the base e).

The ground truth measurements of aerosol content at the time of the NOAA-6 overpasses (approximately 0730 l.s.t.) were made with hand-held sunphotometers at ten sites in close proximity to the ocean. The ground-truth sites and their locations are listed in Table 1.

TABLE 1 Ground-Truth Sites

Site	Longitude	Latitude
Azores	27° 03' W	38° 43' N
Barbados	59° 30' W	13° 10' N
Diego Garcia	72° 29' E	7° 21' S
Fanning Island	159° 23' W	3° 54' N
Guam	144° 50' E	13° 33' N
Kadena (Okinawa)	127° 46' E	26° 21' N
Midway	177° 23' W	28° 12' N
Sable Island	60° 01' W	43° 56' N
San Diego	117° 16' W	32° 45' N
San Juan, P. R.	66° 00' W	18° 27' N

RESULTS

One hundred and fifty-eight useful coincidences between ground truth measurements and the NOAA-6 overpass were obtained during the summer of 1980. To date, the data for four sites have been analyzed and are discussed below.

A Correction for AVHRR Radiance Values

The results for San Diego are plotted in Fig. 2 which shows that the measured radiances (normalized to nadir viewing with a sun zenith angle of 63°) are lower than anticipated, based on the MSS5 regression line for San Diego. However, it is believed that these radiances are low due to radiometric calibration errors in the AVHRR sensor, based on a comparison of the radiances measured in Channels 1 and 2. It was found previously [5] that the radiometric calibration of sensors is a problem in intercomparing the radiance-aerosol content relationship for different satellites. Figure 2 also shows, for comparison, four data points for measurements made from the USNS Hayes off the Virginia coast in April 1980. These data show excellent agreement with the San Diego results even though they are for widely separated locations.

The basis for believing that some error exists in the radiometric calibrations of AVHRR Channels 1 and 2 is illustrated in Fig. 3 which shows the Channel 1 radiances plotted against the Channel 2 radiances for the same ocean pixel without any correction for sun or viewing angles (the Channel 2 radiance is corrected for water vapor absorption). It is seen that the mean curve does not pass through the origin, suggesting that the AVHRR radiance calibrations are in error, since both channels should indicate zero radiance at the same time. Theoretical radiance values are also plotted in Fig. 3 for the same sun and viewing angles of the measured radiances, and indeed indicate that regardless of the aerosol content and size distribution, the mean curves can be extended through the origin. The middle of the dashed curves in Fig. 3 shows where radiances for -0.5N should theoretically lie. The mean of the measured data (the solid curve) can be shifted to this location by adding 0.5 mw/cm^2/μm/sr to Channel 1 radiances, and by subtracting 0.25 mw/cm^2/μm/sr from Channel 2 radiances. It is important to note that these corrections were derived independent of any radiance-aerosol content relationship.

With the corrected values of the Channel 1 radiances, it is seen in Fig. 2 that the normalized radiances show excellent agreement with the Landsat relationship. It is noted that a group of five data points with $N < 0.35$ shows radiances greater than expected. These

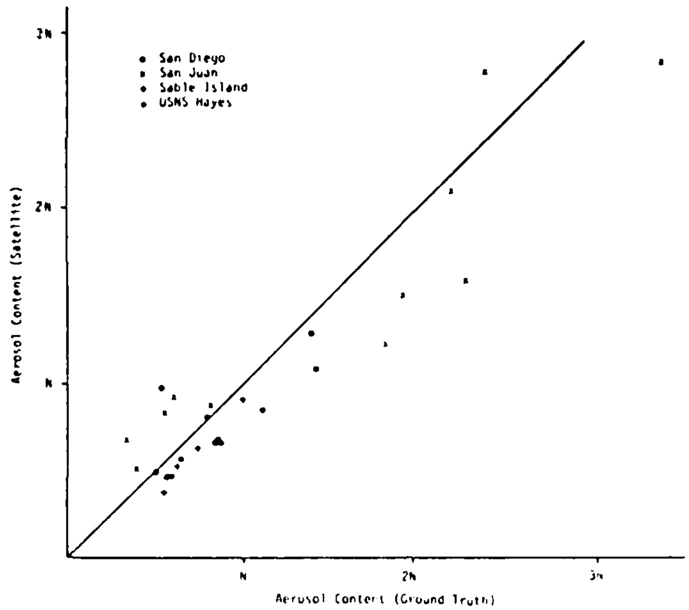


Fig. 2 AVHRR Channel 1 Normalized Radiance vs Aerosol Content at San Diego.

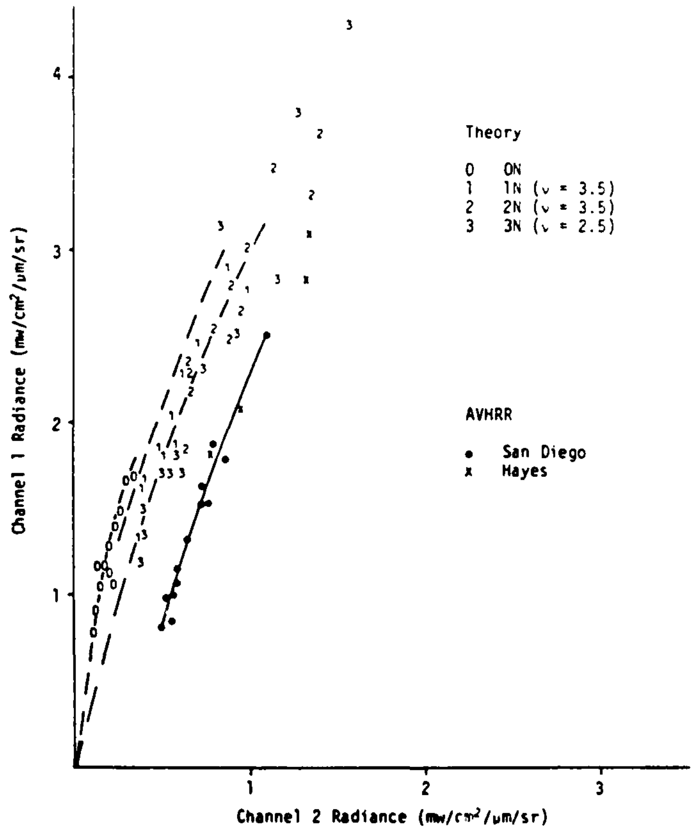


Fig. 3 Theoretical and Measured AVHRR Channel 1 Radiances Versus Channel 2 Radiances.

measurements were obtained for sun zenith angles greater than 73° where the flat earth model used in developing the table-look-up code was expected to introduce uncertainties.

This correction for the AVHRR Channel 1 radiance has been used in the analysis presented in this section. However, it is strictly empirical, and may well be modified when more detailed analyses of the data, and of the AVHRR calibration procedures, are made.

San Diego Results

The ground-truth data obtained at San Diego were very good with excellent agreement within each group of three readings, although 6 of the 17 data sets were obtained for large zenith angles ($\theta_0 < 70°$) where the table-look-up code is expected to introduce uncertainties in the predicted aerosol content due to the use of a flat earth model in the calculations. The results for San Diego are given in Fig. 4, and, neglecting the points for $\theta_0 < 70°$, it is seen that very good agreement (except for one point) is found between the AVHRR (N_S) and ground-truth (N_T) aerosol contents.

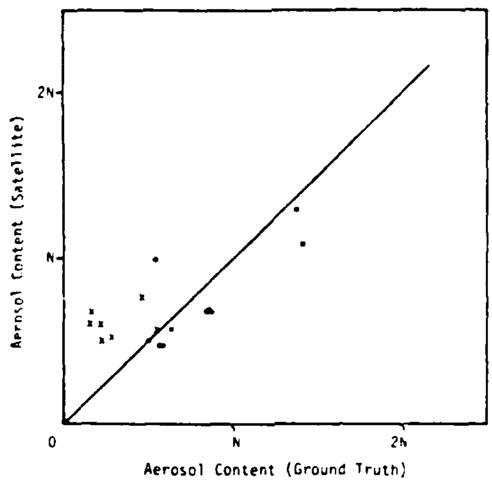


Fig. 4 Comparison of AVHRR and Ground-Truth Measurements of Aerosol Content at San Diego. (X indicates $\theta_0 > 70°$.)

It is seen that there is a good correlation between the satellite and ground-truth measurements, with the satellite generally slightly unoerestimating the aerosol content.

Sable Island Results

Excellent ground-truth data were obtained at Sable Island, but unfortunately cloud cover and satellite data availability limited the number of useful coincidences to four, all of which had $\theta_0 < 70°$. As seen in Fig. 5, there is an excellent correlation between the satellite and ground-truth measurements, again with the satellite underestimating the aerosol content.

San Juan Results

The San Juan results are plotted in Fig. 6 and clearly show a correlation, but with more scatter than seen for the other sites. The ground truth observer did not follow our instructions, and it is believed that the poor ground-truth data are responsible for most of the scatter.

Barbados Results

Very good ground-truth observations were made at Barbados, and although the presence of cirrus was often recorded, the sunphotometer measurements showed excellent agreement within the groups of three. The comparison between the satellite and ground-truth measurements is given in Fig. 7, and shows an excellent correlation. However, it appears that the satellite is significantly overestimating the aerosol content, in contrast with the tendency to underestimate at the other sites.

If this overestimation is due to the aerosol properties being different from those at the other sites and in the table-look-up code, we can estimate these properties based on

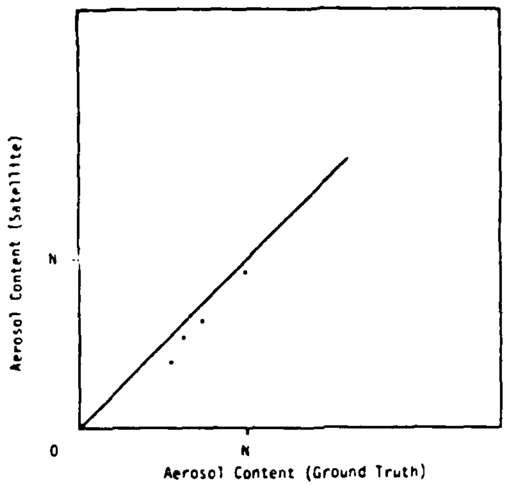


Fig. 5 Comparison of AVHRR and Ground-Truth Measurements of Aerosol Content at Sable Island.

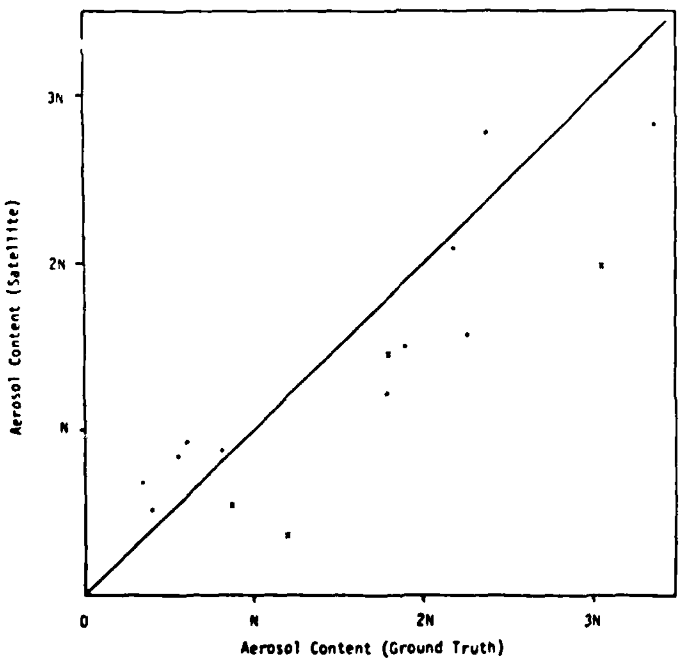


Fig. 6 Comparison of AVHRR and Ground-Truth Measurements of Aerosol Content at San Juan. (X indicates $\theta_o > 70°$.)

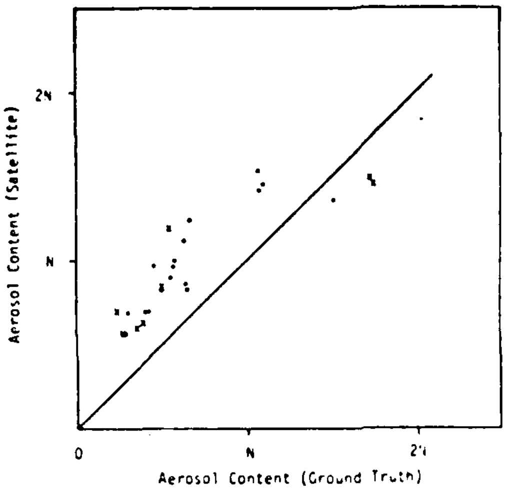


Fig. 7 Comparison of AVHRR and Ground-Truth Measurements of Aerosol Content at Barbados (Sunphotometer I_o = 176). (X indicates $\theta_o > 70°$.)

previous [1] theoretical calculations. If the aerosol refractive index (n) is 1.5, as used in the table-look-up code, then the Junge size parameter (ν) must be about 5.5 to fit the results in Fig. 7, or if ν = 3.5, as used in the table-look-up code, then n ~ 1.7. However, the ground-truth measurements were multispectral at Barbados and allow an estimate of ν to be made; the results generally show ν ~ 2.0 which suggests [8] the presence of Saharan dust in the atmosphere. If ν = 2.0, then the theoretical calculations require n ~ 1.9 in order to fit the results in Fig. 7. This seems unreasonable, especially since Carlson and Caverly [8] indicate that n = 1.54 - 0.005i is representative of Saharan dust. Thus it is difficult to attribute the results in Fig. 7 to differences in the aerosol optical properties enhancing the satellite radiances, and suggests that perhaps there is a systematic error in the sunphotometer measurements.

The sunphotometer, used at Barbados, had I_o = 176 for the 500 nm channel, as measured by an accurate Langley plot at the University of Miami, after the sunphotometer was returned from the Barbados site. This value was used in the reduction of the ground-truth data in Fig. 7. However, if I_o = 206 is used, the satellite and ground-truth measurements show excellent agreement as seen in Fig. 8. This is a large apparent error in the value of I_o, and, according to discussions with T. Snowdon of the University of Miami, unreasonably large.

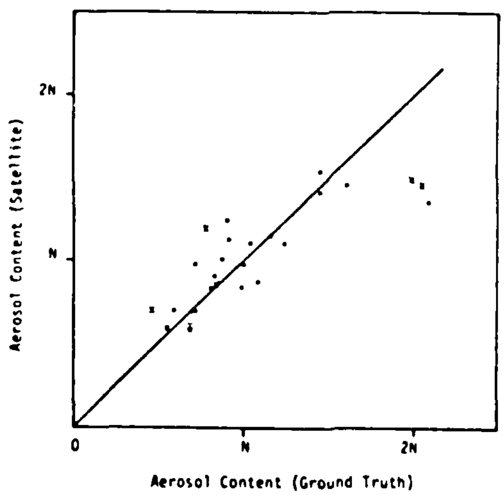


Fig. 8 Comparison of AVHRR and Ground-Truth Measurements of Aerosol Content at Barbados (Sunphotometer I_o = 205). (X indicates $\theta_o > 70°$.)

It is possible that the sunphotometer readings have been misinterpreted due to the presence of more larger particles (as evidenced by $\nu = 2.0$) in the atmosphere, which increase the forward scattering of the incident solar radiation, and thus, reducing the measured value of the optical thickness. Box and Deepak [9] theoretically estimate that for $\nu = 2.0$ the measured optical thickness could be low by about 6% for a sunphotometer with a 2° field of view. Certainly, a correction for this effect to the ground-truth aerosol content in Fig. 7 would make the agreement with the satellite values somewhat better. A combination of this effect and the uncertainty in the I_0 of the sunphotometer appear to be the most likely explanation of the Barbados anomaly, and should be examined in more detail. The size distribution effect may well account for some of the scatter in the results at the other sites.

It is also possible that the AVHRR Channel 1 radiance is enhanced by bottom reflection if the water is shallow or very clear at the Barbados site; this effect was observed at Miami in our Landsat study [1]. It should be possible to detect a bottom effect by comparing a plot of Channel 1 vs Channel 2 radiances for Barbados with that for San Diego (Fig. 3). The bottom effect would enhance the Channel 1 radiance much more than the Channel 2 radiance since water is much less transparent to the longer wavelength radiation. However, the Barbados data show excellent agreement with that of San Diego, strongly suggesting that the bottom effect is not responsible for the Barbados anomaly.

Comparison of Results for the Different Sites

The results for San Diego, Sable Island, San Juan, and the USNS Hayes are shown together in Fig. 9 for coincidences with $\theta_0 < 70°$; the results for Barbados are not included in this comparison due to their unexplained difference from the other sites.

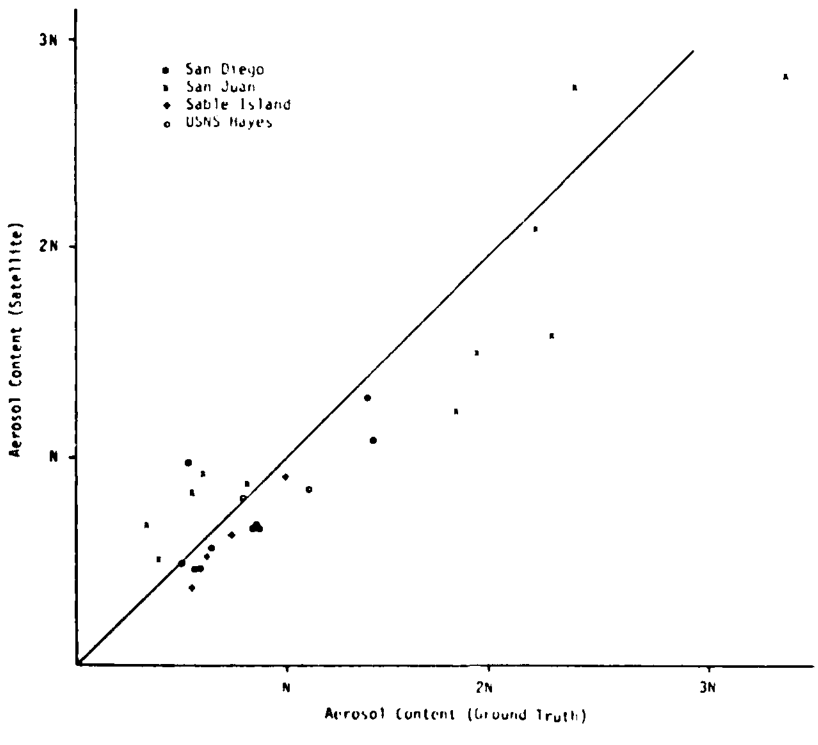


Fig. 9 Comparison of AVHRR and Ground-Truth Measurements of Aerosol Content (for $\theta_o < 70°$).

The intercomparison shows very good agreement between the sites as evidenced by the linear regression line for the data in Fig. 9:

$$N_S = 0.14 + 0.80\ N_T$$

Correlation Coefficient, $r = 0.93$; Standard Error of Estimate, $s_d = 0.25$

It is clear from this limited amount of data, even with the ground-truth problems and other uncertainties, that the AVHRR Channel 1 radiance can be used to obtain a useful measurement of the atmospheric aerosol optical thickness.

AVHRR Measurements of Aerosol Size Distribution

A preliminary investigation has been made into the use of AVHRR Channels 1 and 2 to infer the Junge size distribution parameter (ν) in addition to the aerosol content. Knowledge of the variation of the size distribution of a global basis would aid in the radiative transfer calculations in climate modelling.

In order to infer ν from the satellite data the Channels 1 and 2 radiances (after correcting the Channel 2 radiance for water vapor absorption) are compared with the theoretical radiances for the sun and view angles at the time of the measurement. Model values of N and ν are chosen so that the model radiances agree with the measured radiances in both AVHRR channels.

A comparison of ν from the AVHRR data and from the multispectral USNS Hayes ground-truth is shown in Fig. 10. These are believed to be the first estimates of a tropospheric aerosol size distribution parameter from space, and show excellent agreement with the ground-truth measurements. Of course, many more observations will be required to validate the technique.

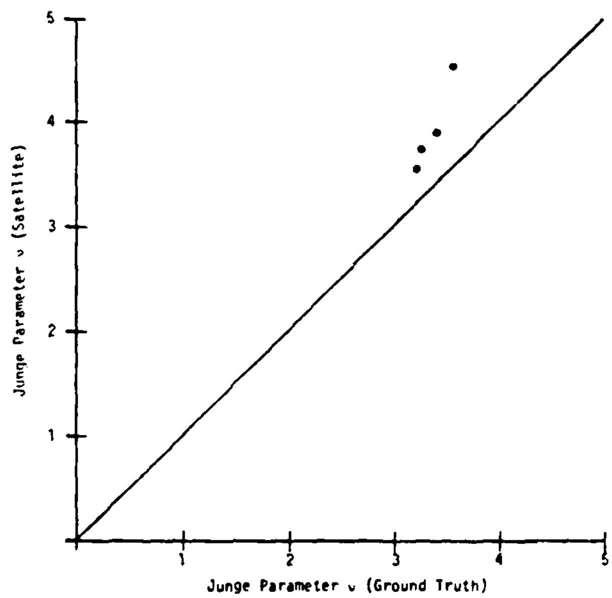


Fig. 10 Comparison of AVHRR and Ground-Truth Measurements of Aerosol Size Distribution (USNS Hayes).

CONCLUSIONS

A large set of AVHRR and ground-truth data was obtained at ten sites around the globe to investigate the possible global variability of the radiance-aerosol content relationship observed previously with Landsat data. The aerosol content was inferred from the AVHRR Channel 1 radiance using an algorithm based on previous Landsat measurements at San Diego. The data for four sites have been analyzed, and show excellent agreement between the aerosol content measured by the AVHRR and by sunphotometers at San Diego, Sable Island and San Juan, but at Barbados, the AVHRR appears to overestimate the aerosol content. The reason for the different relationship at the Barbados site has not been definitely established, but is most likely related to problems in interpreting the sunphotometer data rather than to a real overestimation by the AVHRR.

These results use corrected AVHRR radiances. The correction is a simple empirical one based on a comparison of the Channel 1 and 2 radiances observed over the oceans, and might be modified if a detailed analysis of the correction and the AVHRR radiometric calibration procedures is made.

Some preliminary results suggest that useful information on the aerosol size distribution can be obtained from analysis of the Channel 1 and 2 radiances. This information would greatly add to the usefulness of the aerosol content measurements in climate-directed radiative transfer calculations.

ACKNOWLEDGEMENTS

The global experiment and analysis were sponsored by NOAA Contract MO-A01-78-00-4092, and the USNS Hayes measurements and the two-channel analysis were sponsored by ONR Contract N00014-77-C-0489.

REFERENCES

1. M. Griggs, Determination of Aerosol Content in the Atmosphere from Landsat Data, Final Report; Contract No. NAS5-20899 (January 1978).

2. P. Koepke and M. Quenzel, J. Geophys. Res. 34, p. 7847 (1979).

3. C. C. Norton, F. R. Mosher, B. Hinton, D. W. Martin, D. Santek and W. Kuhlow, J. Appl. Meteorol. 19, p. 633 (1980).

4. M. Griggs, J. Air Poll. Contr. Assoc. 25, p. 622 (1975).

5. M. Griggs, J. Atmos. Sci. 36, p. 696 (1979).

6. L. Elterman, "Atmospheric Optics," Handbook of Geophysics and Space Environments, S. Valley, Ed., McGraw-Hill, 7-1 to 7-2 (1965).

7. J. V. Dave, Appl. Optics 9, pp. 1457, 1888, and 2673 (1970).

8. T. N. Carlson and R. S. Caverly, J. Geophys. Res. 82, p. 3141 (1977).

9. M. A. Box and A. Deepak, Appl. Optics 18, p. 1941 (1979).

MED

83